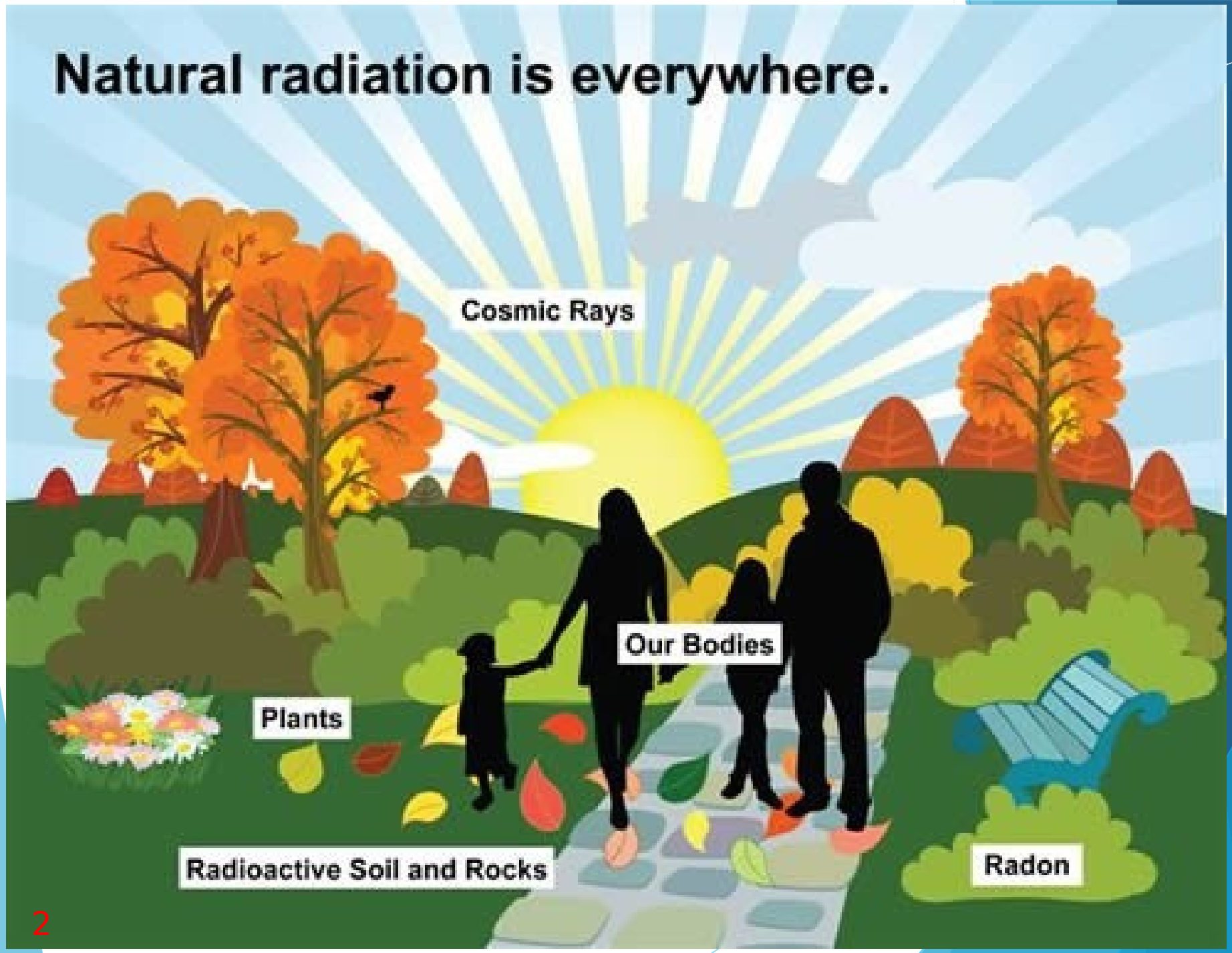
Our Radioactive World

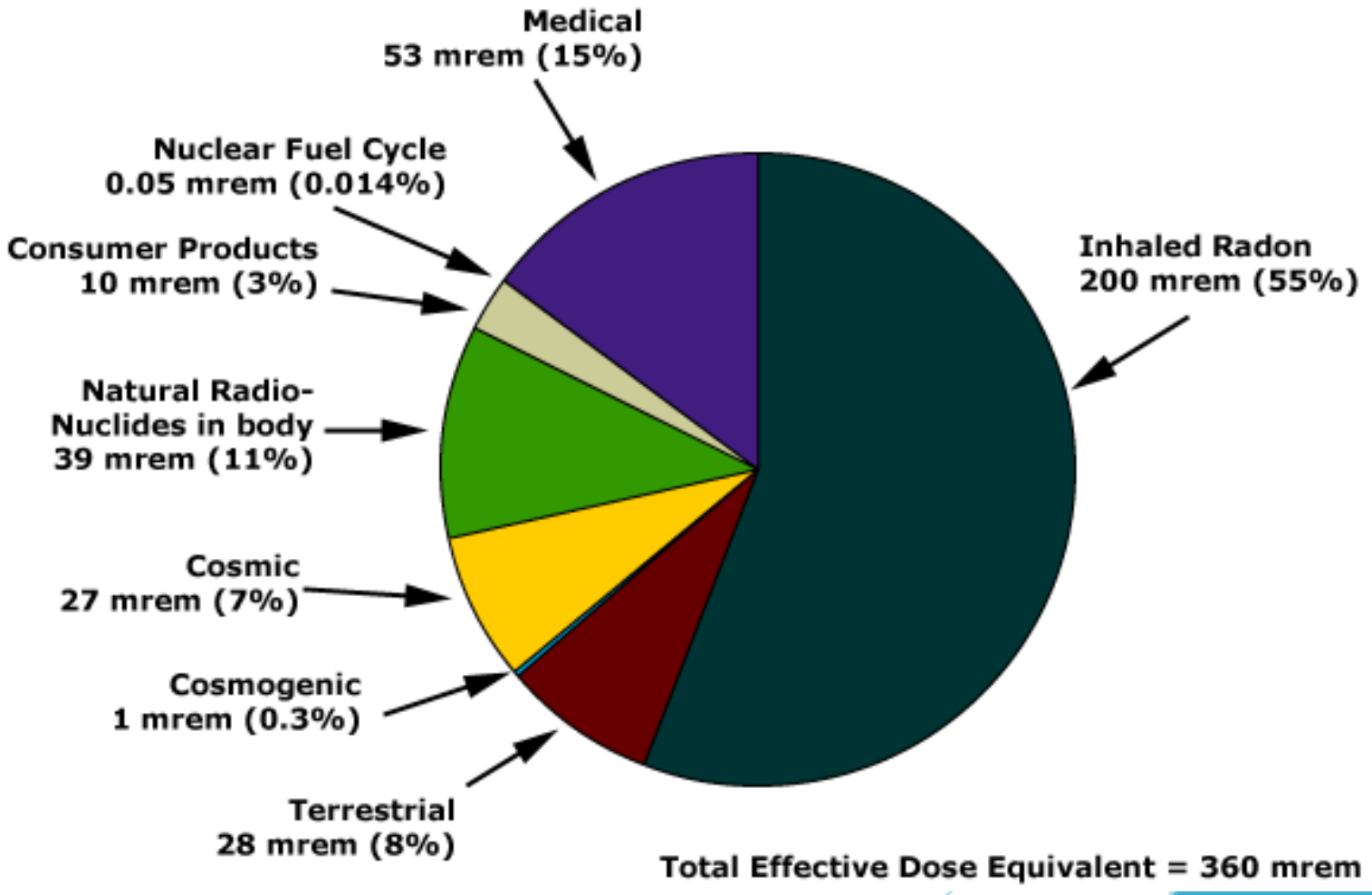
Jeffrey Mahn

Nuclear Engineer (Retired)

jamahn47@gmail.com


Natural radiation is everywhere.
Cosmic Rays
Our Bodies
Plants
Radioactive Soil and Rocks
Radon

Sources of Background Radiation



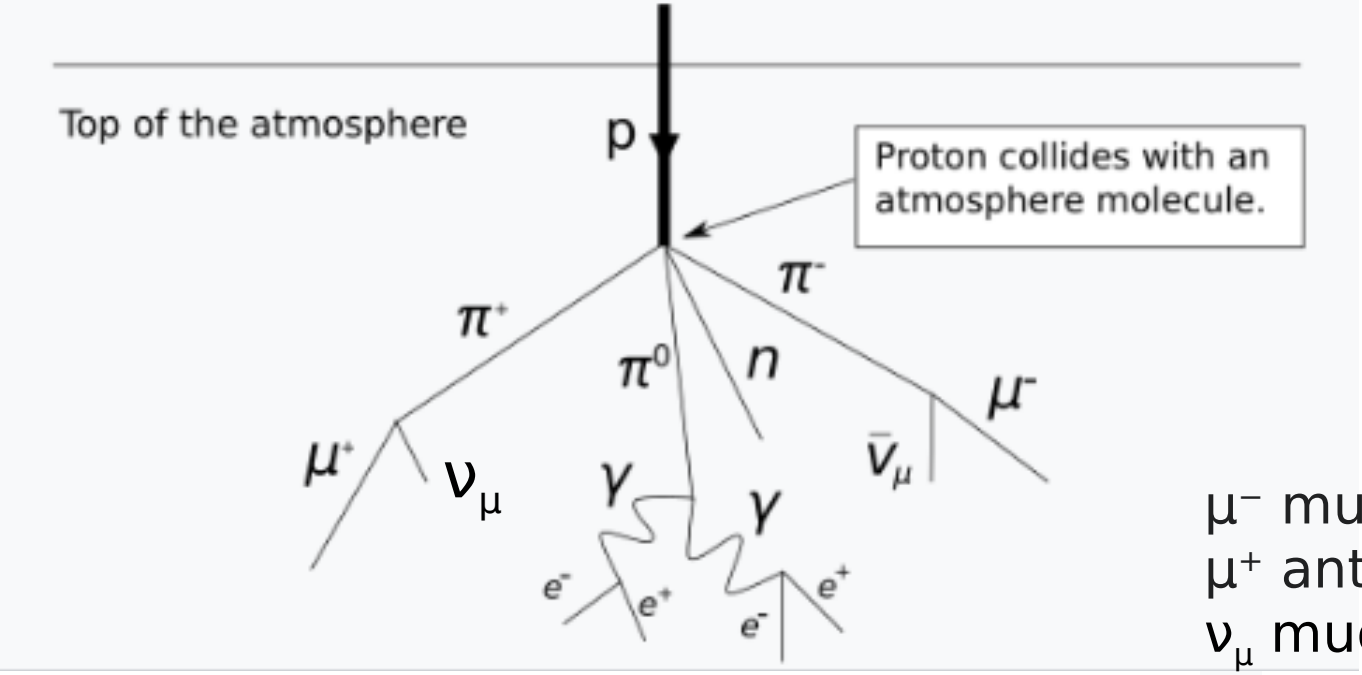
Cosmic and Cosmogenic Radiation

Cosmic Radiation

- Composition
  - 89% protons
  - 9% alpha particles
  - 1% electrons
  - 1% heavy element nuclei
- Interactions with atoms in upper atmosphere produce muons, electrons, positrons, neutrinos, and neutrons
  - Muons traveling at essentially speed of light constitute ≈80% of natural background dose from cosmic radiation*
  - Electrons produced by muons, or present in electromagnetic cascade, primary contributor to remainder of charged-particle cosmic radiation background dose*

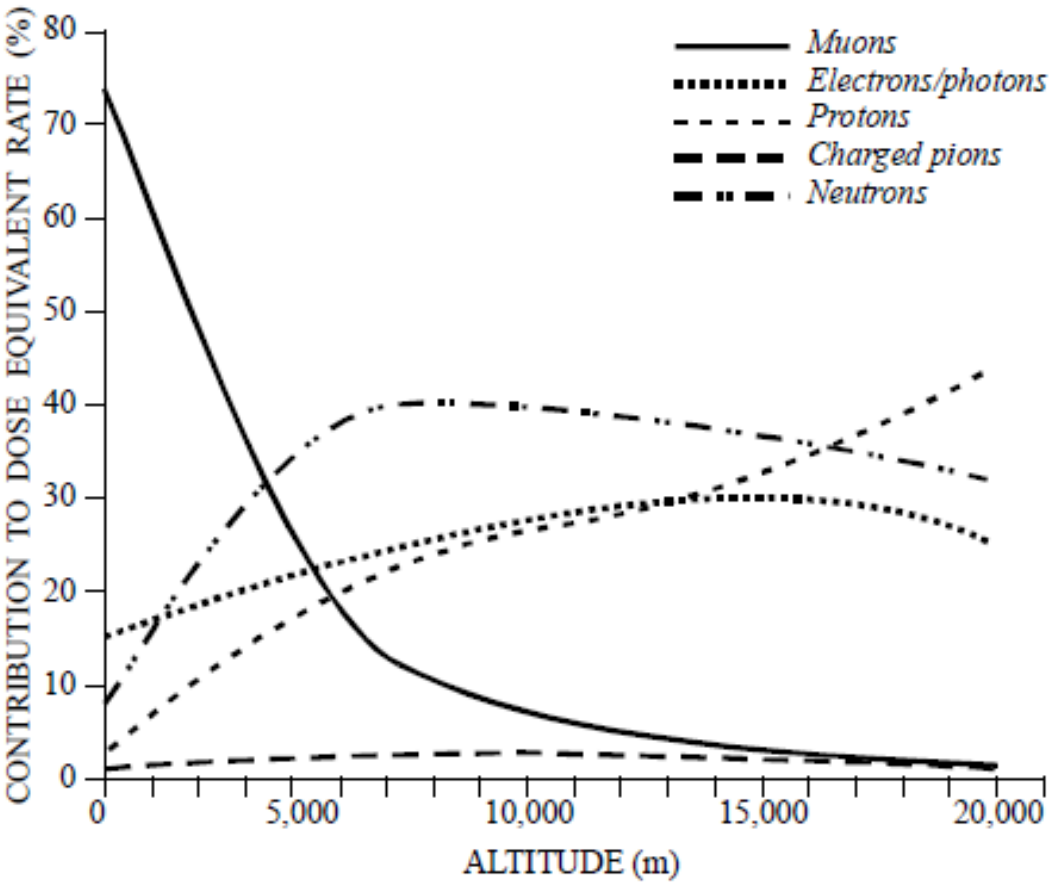
* UNSCEAR 2000 Report, Sources and Effects of Ionizing Radiation, Annex B, Exposures from
Natural Radiation Sources

Cosmic Particle Shower



μ⁻ muon
μ⁺ antimuon
ν_μ muon neutrino
$\bar{\nu}_\mu$ muon antineutrino
e^- electron
e^+ positron

Components of Dose Equivalent Rate from Cosmic Rays in Atmosphere

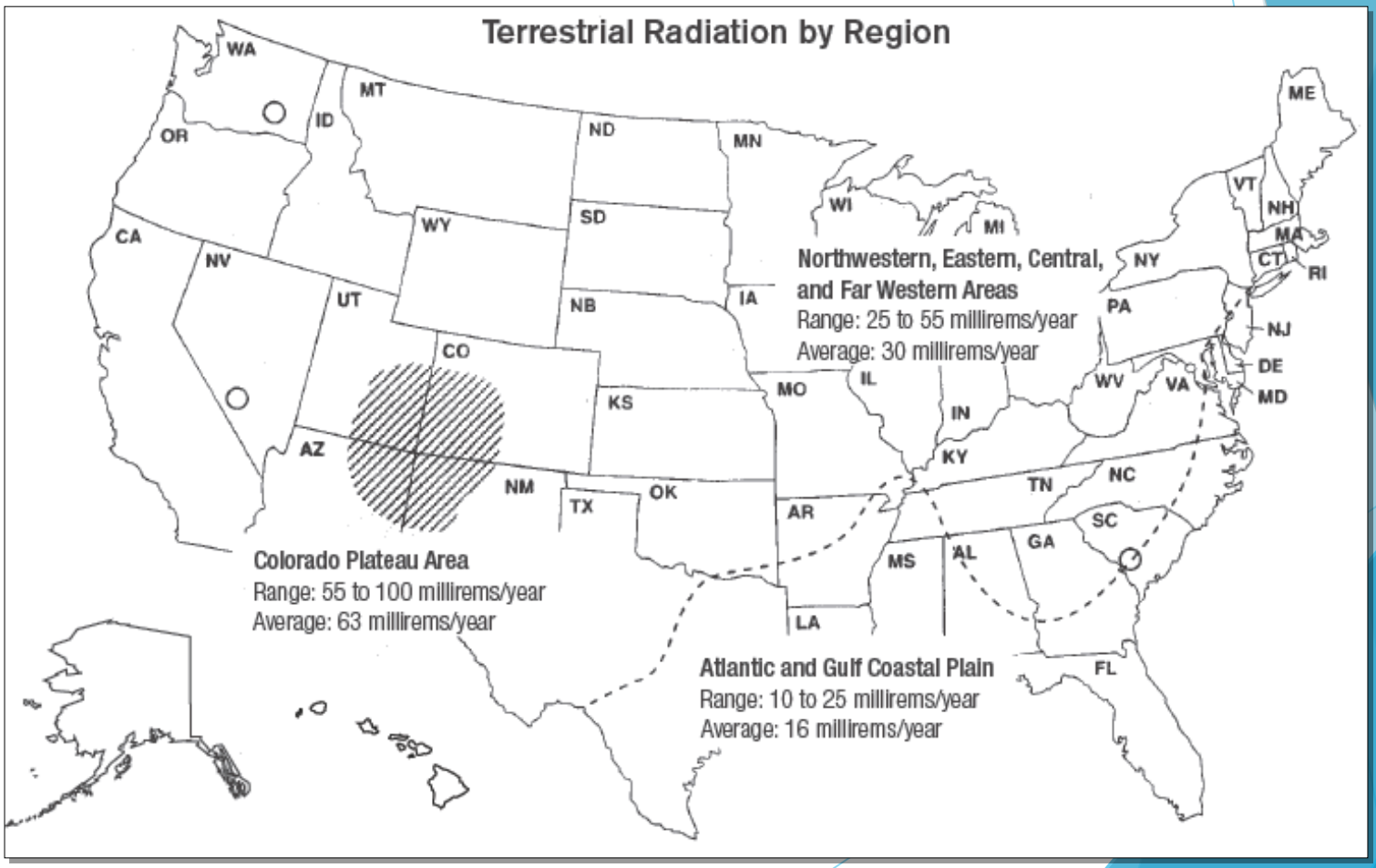


Ref. UNSCEAR 2000 Report, Sources and Effects of Ionizing Radiation, Annex B, Exposures from Natural Radiation Sources

Terrestrial Radiation

Who is exposed to the most terrestrial radiation?

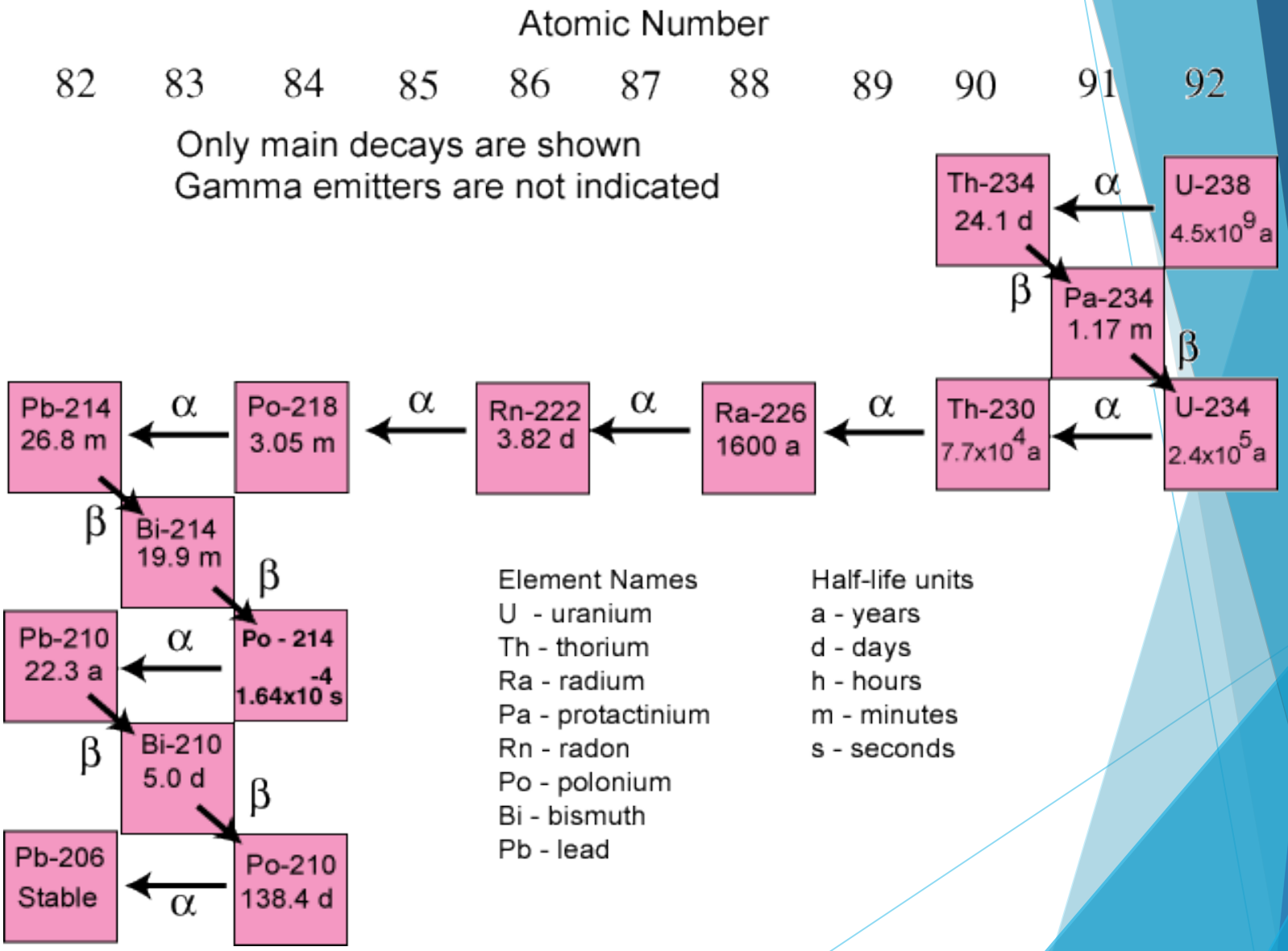
Terrestrial radiation comes from long-lived radioactive isotopes like potassium, uranium, and thorium (as well as their radioactive decay daughter products), found in most soils.



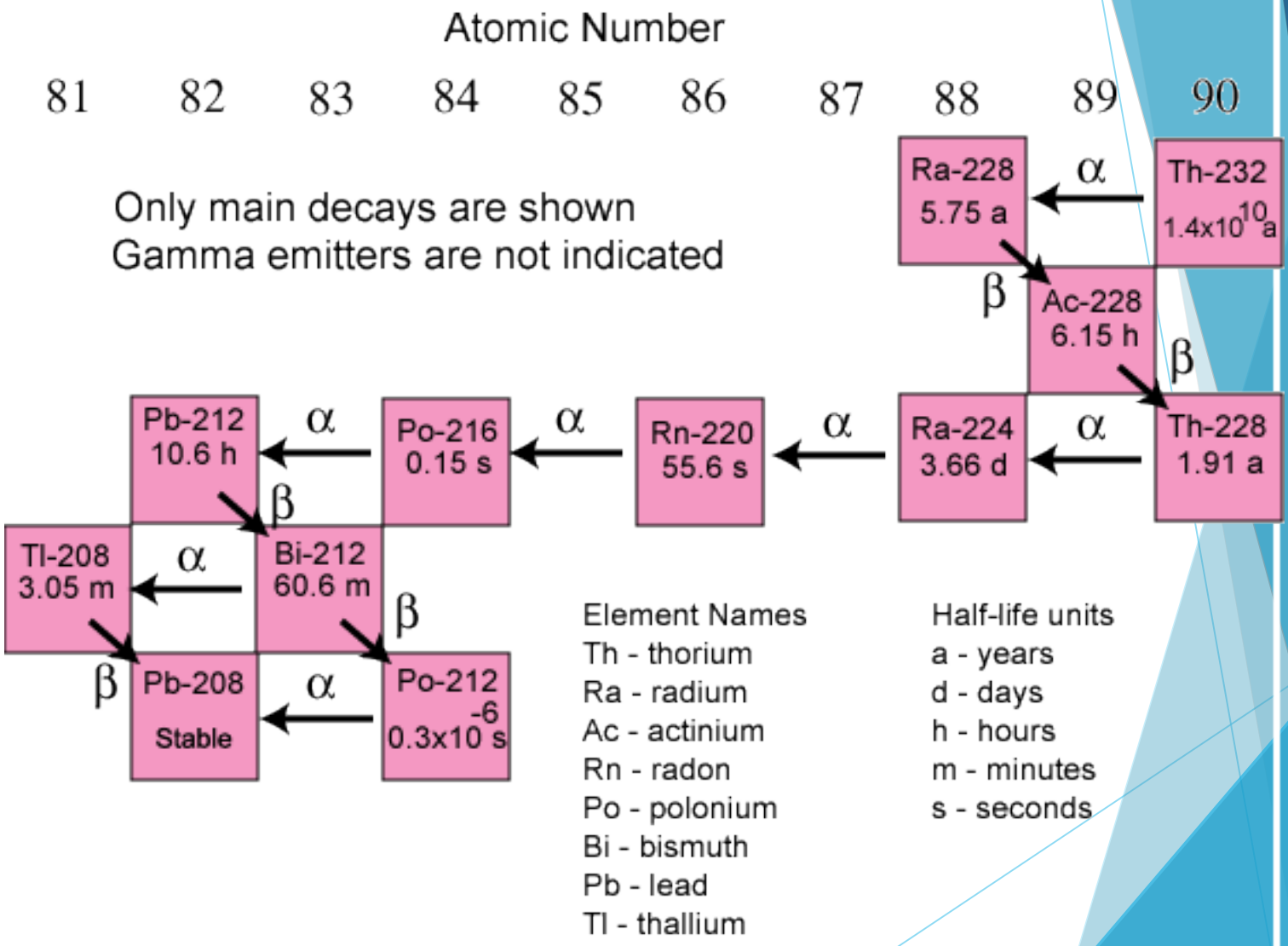
Terrestrial Sources of Radiation

Isotope	Half-life (years)	Radiation
Ra-226	1622	α, γ
U-238	4.5×10^{9}	α
Th-232	1.4×10^{10}	α
K-40	1.3×10^{9}	β, γ
Rb-87	4.7×10^{10}	β
La-138	1.1×10^{11}	β, γ
Lu-176	2.1×10^{10}	β, γ

The Uranium-238 Decay Chain



The Thorium-232 Decay Chain



Internal Radiation

Natural Radioactivity in the Body

Nuclide	Total Activity of Nuclide in the Body
Uranium	30 pCi (1.1 Bq)
Thorium	3 pCi (0.1 Bq)
Potassium-40	120,000 pCi (4440 Bq)
Radium-226	30 pCi (1.1 Bq)
Carbon-14	100,000 pCi (3700 Bq)
Tritium	600 pCi (22.2 Bq)
Polonium	1,000 pCi (37 Bq)

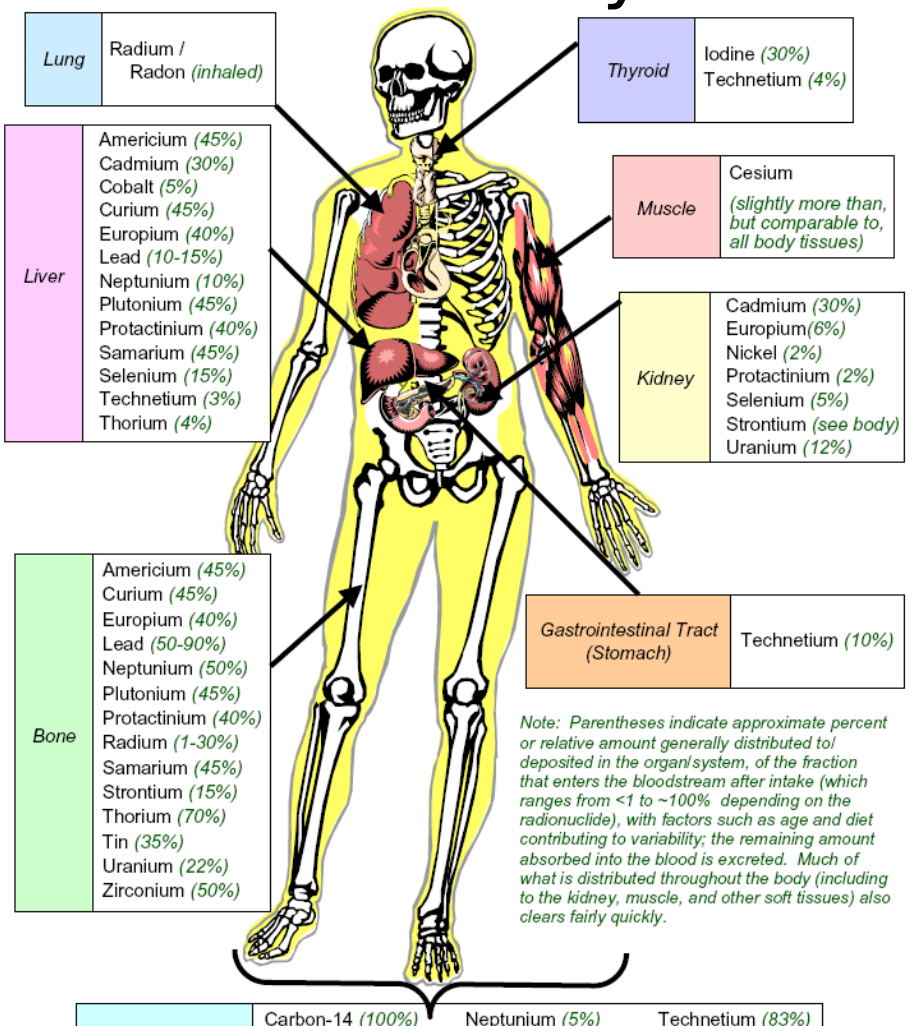
Estimated concentrations of radionuclides calculated for a 70-kilogram adult based on ICRP 30 data

Radioactive Elements in Human Body

Radioactive Isotope	Half Life (years)	Isotope Mass in the Body (grams)	Element Mass in the Body (grams)	Activity within the Body (Disintegrations/sec)
Potassium-40	1.26×10^{9}	0.0165	140	**4,340**
Carbon-14	5,730	1.6×10^{-8}	16,000	**3,080**
Rubidium-87	4.9×10^{10}	0.19	0.7	**600**
Lead-210	22.3	5.4×10^{-10}	0.12	15
Tritium (H-3)	12.43	2×10^{-14}	7,000	**7**
Uranium-238	4.46×10^{9}	1×10^{-4}	1×10^{-4}	3 - 5
Radium-228	5.76	4.6×10^{-14}	3.6×10^{-11}	5
Radium-226	1,620	3.6×10^{-11}	3.6×10^{-11}	3

Source:
http://www.rerowland.com/BodyActivity.htm

Distribution of Selected Radionuclides in Body

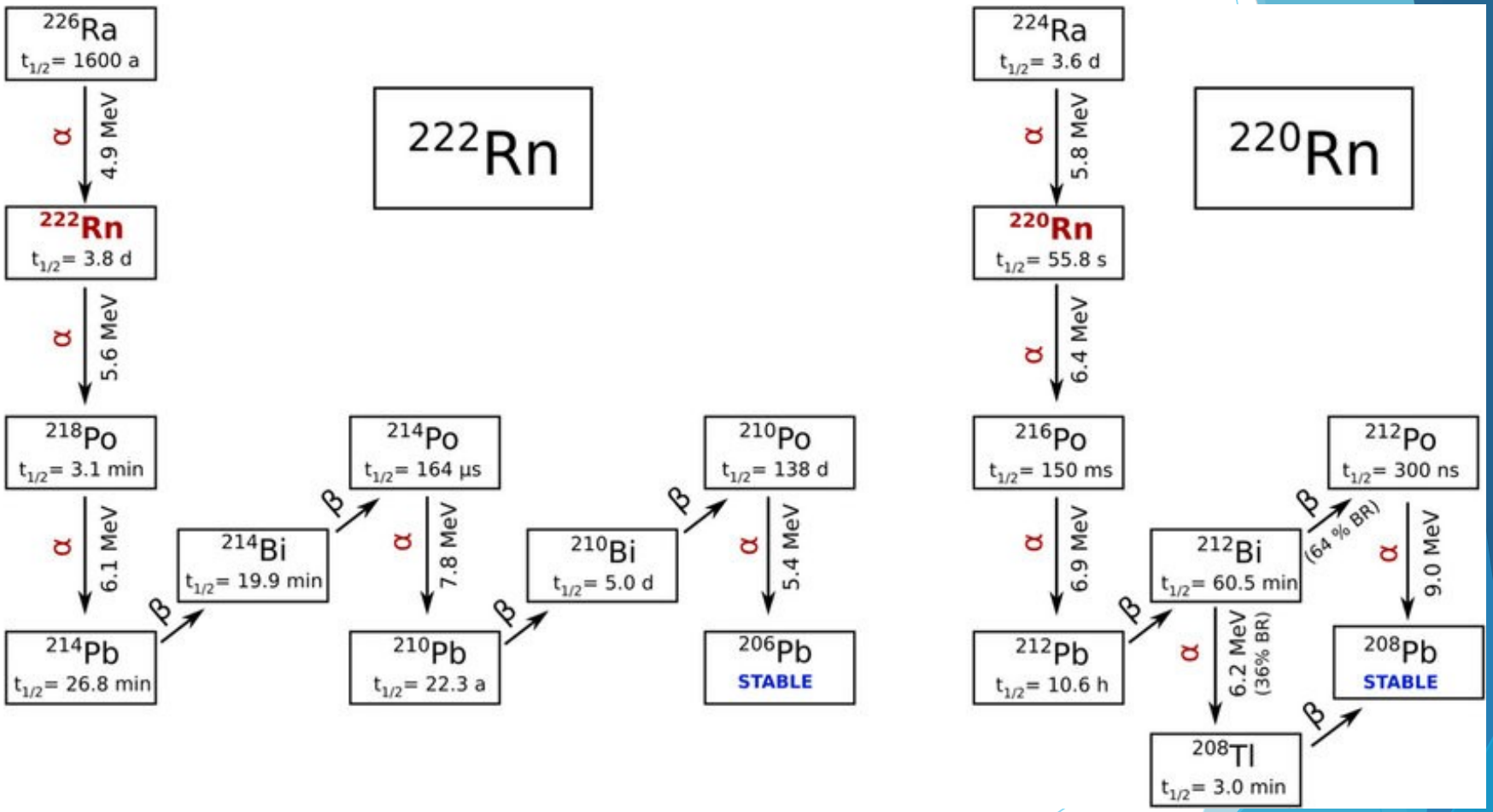


Inhaled Radiation (Radon)

What is Radon?

- Radon is radioactive noble gas that enters atmosphere from radioactive decay of radium contained in rocks and soil
- Radon-222 (Rn-222), with half-life of 3.8 days, arises from radioactive decay of radium-226
- Radon-220 (Rn-220), with half-life of 55.8 seconds, arises from radioactive decay of radium-224
- Internal exposure from radon and short-lived solid radioactive isotopes (next slide) remaining in lung tissue from radon radioactive decay constitute largest contributor to U.S. natural background radiation exposure

Radon Decay Chains



What is Radon? (cont.)

- Half-lives of Rn-222 and Rn-220 isotopes as well as various decay radioisotopes important for determining relative contributions to bronchial dose
  - Timeframe for diffusion of short-lived Rn-220 in soils results in some decay to non-gaseous radioisotopes before reaching soil surface
  - Very short half-life of Rn-220 means little travel distance from origination site to immediate environment of human beings before decay to non-gaseous radioisotopes
- Half-life differences of radioisotopes from Rn-222 and Rn-220 decay produce very different atmospheric distributions of potentially aerosolized decay products

What is Radon? (cont.)

- Exposure mostly from alpha particles emitted by solid radioisotope progeny of radon decay in lungs; some beta particles and gamma-rays also emitted
  - General agreement that alpha particles responsible for lung cancer seen in miners
- Almost all radon level measurements expressed as concentration of radon in picocuries per liter (pCi/L) of air or in becquerels per cubic meter (Bq/m^3) of air

Radon Exposure in a Nutshell

- Radon exposure is chronic low-dose ionizing radiation exposure
- Chronic low-dose radiation exposures do not inhibit ability of body's adaptive protection mechanisms to repair radiation-induced cell damage (otherwise, we would not be here)
- Exposure to radon (indoor and outdoor) does not result in adverse health effects

Medical Radiation

Medical Radiation Exposure

Medical source most widely varying constituent of natural background ionizing radiation exposure found in literature

- Most common exposure from teeth and broken bone low-dose x-rays
- Nuclear medicine diagnostic imaging procedures result in harmless low-dose exposures
- High-dose exposures from therapeutic radiology procedures (cancer treatment)
- Estimate of ≈50 mrem annual exposure likely average for U.S. population

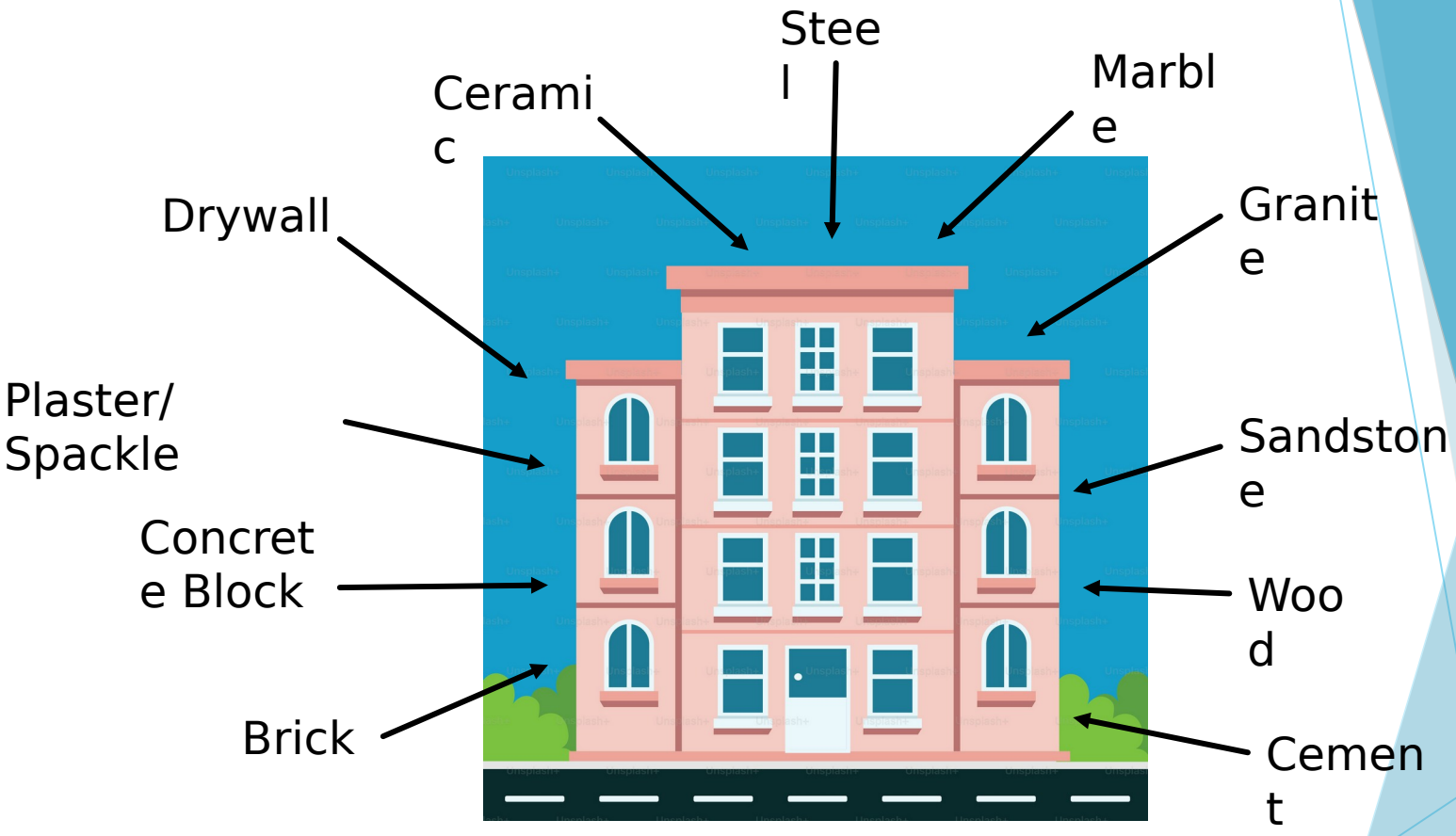
Consumer Product Radiation

Radiation in the Home

Natural Radioactivity in Consumer Products

Consumer Product	Natural Radionuclide
Smoke detector	^{241}Am
Watches and clocks	^{3}H, ^{147}Pm
Photocopier	^{210}Po
Granite countertop	^{238}U, ^{234}U, ^{232}Th, ^{230}Th, ^{226}Ra
Compact fluorescent light bulbs	^{147}Pm, ^{84}Kr, ^{3}H
Ceramic materials (e.g., tiles)	^{238}U, ^{234}U, ^{232}Th, ^{230}Th, ^{226}Ra, ^{40}K
Glassware	^{232}Th, ^{228}Ra, ^{40}K
Water softener salt	^{40}K

Radioactive Building Materials



Small amounts of naturally radioactive elements like uranium, thorium, and their radioactive decay products are found in common building materials.

Typical Radioactivity in Common Building Materials

Material	U-238 (pCi/g)	Th-232 (pCi/g)	K-40 (pCi/g)
Granite	1.7	0.22	32
Sandstone	0.2	0.19	11
Cement	1.2	0.57	6.4
Limestone concrete	0.8	0.23	2.4
Sandstone concrete	0.3	0.23	10
Dry wallboard	0.4	0.32	2.4
By-product gypsum	5.0	1.8	0.2
Natural gypsum	0.4	0.2	4
Wood	--	--	90
Clay Brick	3	1.2	18

Estimates of concentrations of uranium, thorium and potassium in
building materials (NCRP 94, 1987)

Natural Radioactivity in Food

Food group	Natural radionuclide
Beverages	^{210}Pb, ^{210}Po, ^{226}Ra, ^{238}U
Cereals	^{40}K, ^{210}Pb, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U
Fish and shellfish	^{210}Pb, ^{210}Po, ^{226}Ra, ^{234}U, ^{238}U, ^{40}K
Fruit	^{14}C, ^{210}Pb, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U, ^{40}K
Game/venison meat	^{210}Po
Honey	^{14}C
Meat	^{40}K, ^{210}Pb, ^{210}Po, ^{226}Ra, ^{234}U, ^{238}U
Milk and dairy products	^{14}C, ^{40}K, ^{210}Pb, ^{210}Po, ^{226}Ra, ^{234}U, ^{238}U
Vegetables	^{40}K, ^{210}Pb, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U

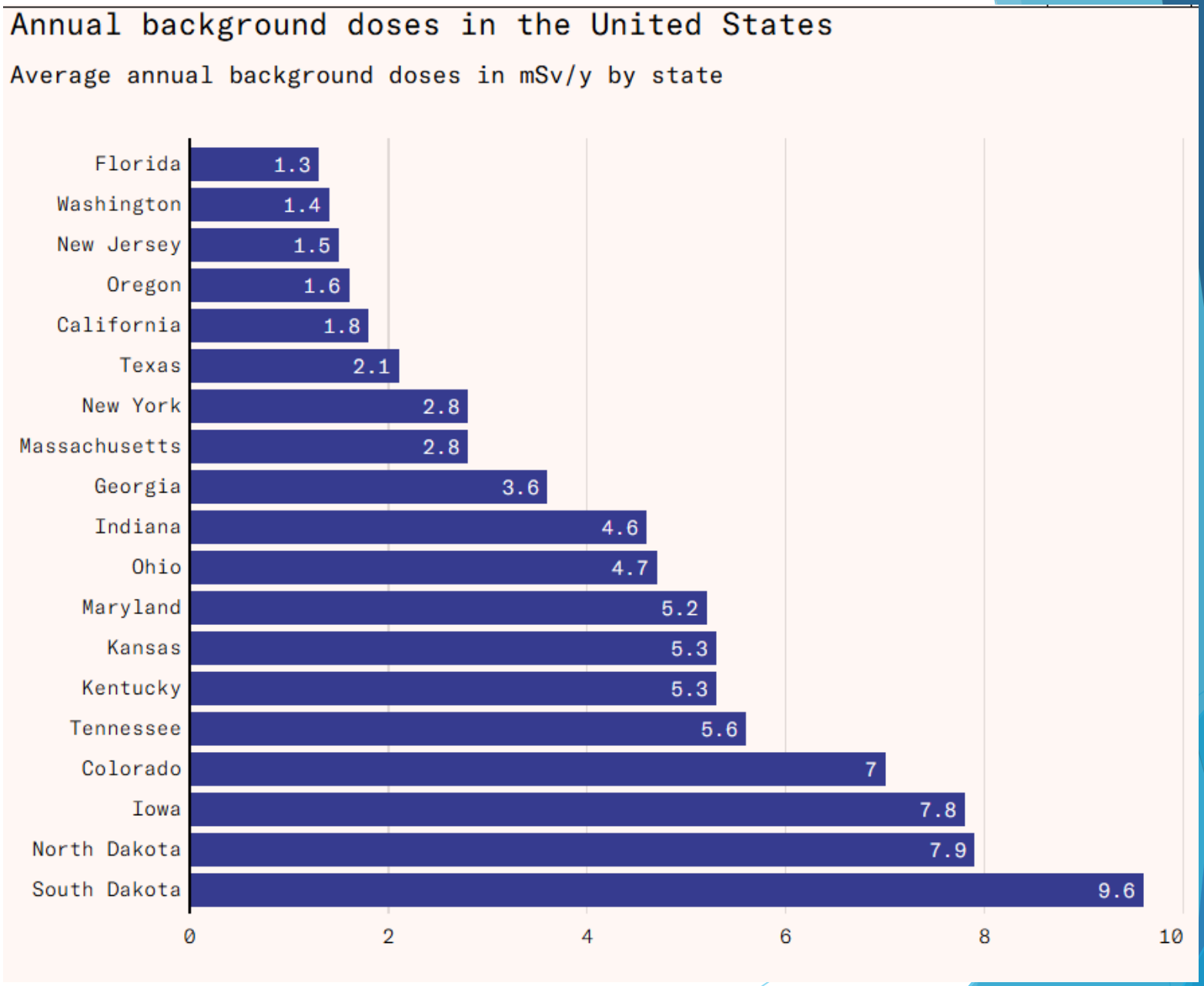
Natural Radioactivity in Food (cont.)

Food	^{40}K (βγ) pCi/kg	^{226}Ra (α) pCi/kg
Brazil Nuts	5600	1000-7000
Lima Bean	4640	2-5
Banana	3520	1
White Potato	3400	1-2.5
Carrot	3400	0.6-2
Red Meat	3000	0.5
Low-sodium Salt	3000	---
Beer	390	---
Drinking Water	---	0-0.17

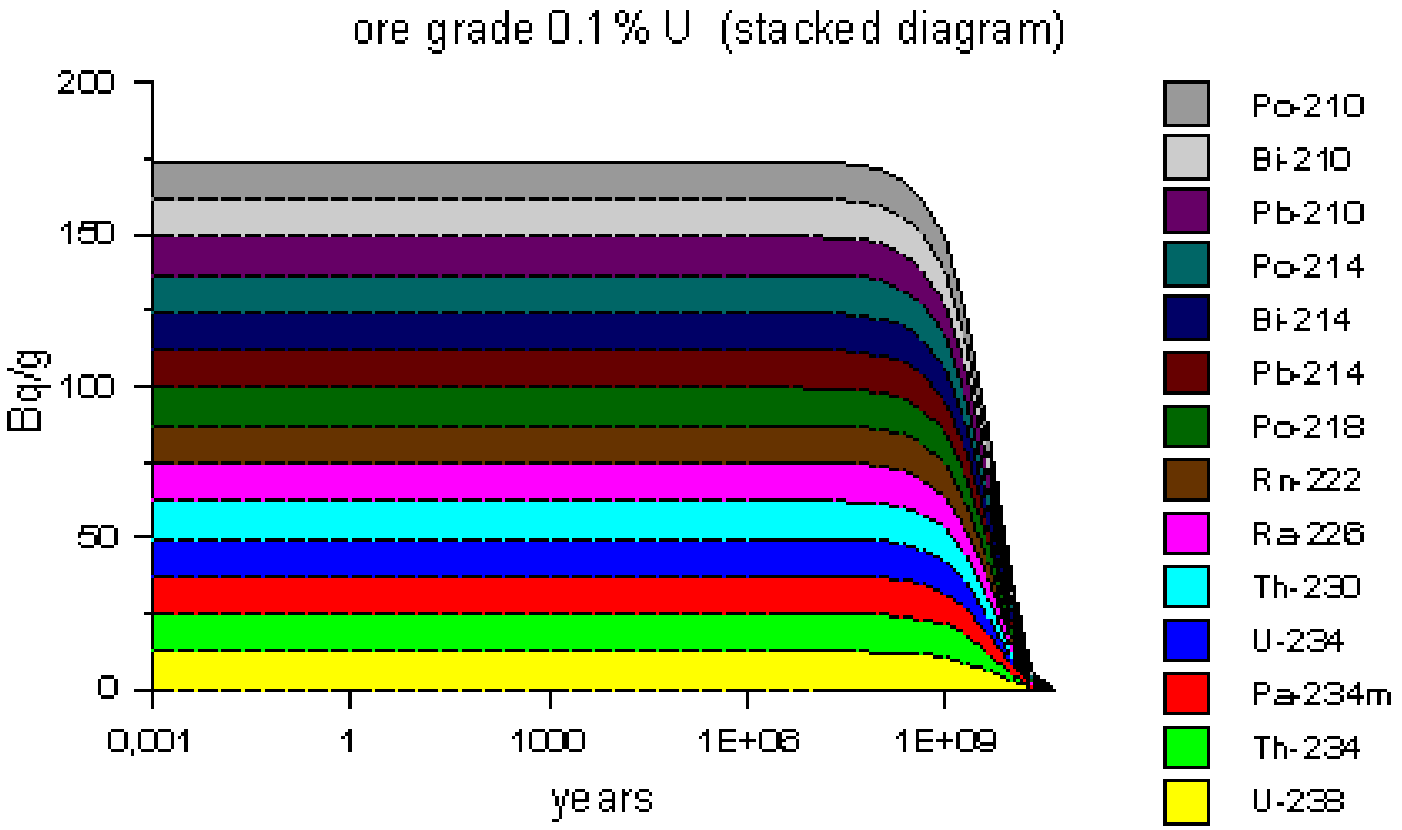
Conclusion

- Humans have lived in world of radioactive elements for extremely long time
- Fact that humans continue to survive and thrive in low-dose radiation environment is testament to fact that naturally occurring ionizing radiation not health risk
- Low-dose radiation from medical procedures not uniquely different from natural background radiation and not harmful to human health

Supplemental Slide


Annual background doses in the United States
Average annual background doses in mSv/y by state
Florida 1.3
Washington 1.4
New Jersey 1.5
Oregon 1.6
California 1.8
Texas 2.1
New York 2.8
Massachusetts 2.8
Georgia 3.6
Indiana 4.6
Ohio 4.7
Maryland 5.2
Kansas 5.3
Kentucky 5.3
Tennessee 5.6
Colorado 7
Iowa 7.8
North Dakota 7.9
South Dakota 9.6
0
2
4
6
8
10

Uranium Ore Activity



U-238 progeny in <u>secular equilibrium</u> with U-238

- Equal production rate and decay rate for each daughter isotope
- Daughter activity governed by U-238 activity